Vertical Root Fracture Detection Using Limited-FOV Cone-beam Computed Tomography

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MASTER'S THESIS

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ABSTRACT

Introduction: Vertical root fractures (VRF) often occur in endodontically treated teeth and are difficult to definitively diagnose. Limited-field of view (FOV) cone beam computed tomography (CBCT) might be promising in the identification of VRFs. **Methods:** Fifty-two single rooted teeth with single canals were used. The experimental group consisted of teeth with naturally existing and artificially induced fractures. Twenty-six non-fractured teeth served as the control group. Specimens were instrumented and imaged with a limited-FOV CBCT and 2 periapical radiographs. Two board certified endodontists and one oral and maxillofacial radiologist evaluated the presence or absence of VRFs. Kappa values comparing the true nature of the specimen with examiner interpretation of the images were determined. Sensitivities and specificities, and inter-examiner reliability were calculated. **Results:** Low kappa values indicated examiners' inability to accurately detect VRFs. Poor agreement among examiners indicated low precision in detecting VRFs with CBCT and PAs. The average sensitivity and specificity for the detection of VRFs using CBCT and PAs was 0.42 and 0.27, respectively. The sensitivities in detecting VRFs with the CBCT of complete versus incomplete fractures were 0.83 and 0.32, respectively. **Conclusion:** Examiners were neither accurate nor precise in detecting VRFs with CBCT scans and PAs. VRFs could not be predictably identified with current limited-FOV CBCT technology unless there was a visible separation of tooth segments.

Key Words: Vertical root fracture, radiographs, CBCT

INTRODUCTION

A vertical root fracture (VRF) extends from the root canal to the periodontium in a longitudinal orientation along the root (1). The prevalence in extracted endodontically treated teeth is 10.9% (2). Mandibular and maxillary premolars, and mesial roots of mandibular molars are more prone to fracture when radicular dentin is removed during endodontic procedures and/or post space preparations (3).

Definitively diagnosing VRFs is difficult. The patient's dental history and diagnostic tests assist in diagnosing VRFs. Tests include trans-illumination, staining, biting, surgery, and periodontal probing (4,5). Diagnosing a VRF often requires multiple periapical radiographs. However, evaluating a three-dimensional object with a two-dimensional modality is limited due to superimposition of additional roots, restorative materials or other anatomical structures. Although multiple radiographs enable a more accurate diagnosis (6), VRFs often remain undetected unless the X-ray beam is within 4 degrees of being parallel to the fracture (7).

Cone-beam computed tomography (CBCT) has aided in detecting second mesiobuccal canals (8), diagnosing apical pathosis (9,10), assessing external root resorption (11) and locating calcified canals. Images provide a 3-dimensional representation of an object and views from a 2-dimensional axial, coronal, and sagittal perspective (12). Relative to medical CT scanners, CBCT systems obtain images with reduced radiation exposure to the patient (13-15). CBCT systems offer different fields of view (FOV) or scan volumes. Lower radiation exposure, shorter reconstruction times, and increased spatial resolution are advantages of a limited-FOV system (16). In a joint position statement regarding the use of CBCT in Endodontics, the American Association of Endodontists and American Association of Oral and Maxillofacial Radiology recommend clinicians use a limited-FOV CBCT for endodontic applications in order to maximize resolution while reducing radiation exposure to the patient (17).

Recent studies demonstrated that large-FOV CBCT systems can detect VRFs more predictably than periapical radiographs. One case series employed limited-FOV systems and combined information gained from a clinical exam to make a diagnosis (18). Another used artificially induced root fractures, which may be larger than fractures that present clinically (19). To date, there are no published studies, which evaluate the ability of a limited FOV CBCT to produce an image that shows a VRF when one exists. The purpose of this study was to determine the accuracy and precision of detecting vertical root fractures using a limited-FOV CBCT.

MATERIALS AND METHODS

This study consisted of 52 extracted, de-identified, single-rooted teeth. Specimens were screened radiographically (Kodak RVG 6100, Carestream Health Inc., Rochester, NY) to ensure the presence of one canal. Specimens were decoronated using separating discs (GFC, Carlstadt, NJ) to a standard length of 14mm, measured from the anatomic apex. All canals were instrumented with 0.04 taper ProFile (DENTSPLY Tulsa Dental Specialties, Tulsa, OK) nickel titanium rotary files to a master apical file size of #45 while irrigating with saline and recapitulating with a #10 Flex-O-File (DENTSPLY Maillefer, Tulsa, OK).

The presence or absence of pre-existing vertical root fractures (VRFs) was determined using trans-illumination (Microlux, AdDent, Danbury, CT), the application of dye (ToDyeFor, Roydent, Johnson City, TN), and examination under a dental operating microscope (DOM) (14x magnification) (Global Surgical Corporation, St. Louis, MO). A random sequence generator was used to assign specimens to an experimental group (teeth with VRF) or the control group (teeth without VRF).

Teeth with pre-existing fractures were placed into the experimental group and VRFs were artificially created in the remaining teeth assigned to this group. Fractures were made after specimens were embedded in heavy body polyvinylsiloxane (PVS) putty (Examix, GC America Inc, Alsip, IL) and placed into a ¾-inch diameter copper ring. A tapered wedge was inserted into the canal and force applied until visual, auditory, and/or tactile evidence of a fracture was observed. Artificial fractures were confirmed using trans-illumination, dye and examination under DOM (14x magnification).

An artificial socket was created in a solid foam mandible (Pacific Research Laboratories Inc, Vashon, WA). Two layers of boxing wax (Coltene/Whaledent Inc, Cuyahoga Falls, OH) were placed on the mandible to simulate soft tissue. Specimens were secured in the socket with PVS. The mandible was placed in a positioning device securing the mandible and a size #2 CMOS digital sensor in place to ensure the standardization of all images. Using identical settings for all digital radiographs (3 pulse, 70kVP, 7mA sec), two images were exposed for each specimen (Gendex GX 770, Lake Zurich, IL). The first image was exposed using a paralleling technique, and a second image was exposed at a distal horizontal angulation of 15 degrees (see Figure 1). Specimens were placed in a positioning device and scanned with a limited-FOV CBCT (Kodak 9000, Carestream Health Inc., Rochester, NY) with the following settings: 63kV, 4mA, 10.80-second exposure time, 3X5cm FOV, voxel size (resolution) 0.076mm (see Figure 2).

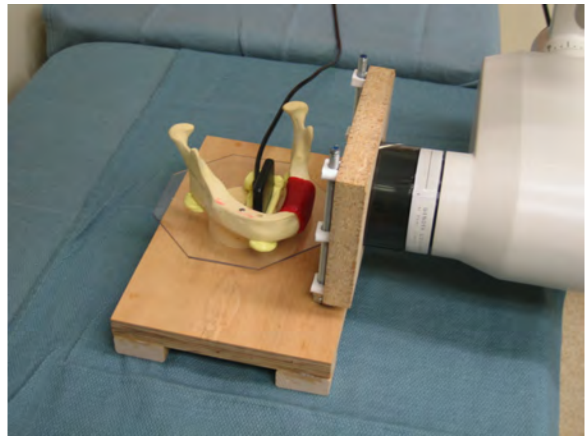

Figure 1.

Figure 2.

Two board certified endodontists and one board certified oral and maxillofacial radiologist were calibrated to recognize VRFs in both imaging formats and to become proficient in using the software tools (brightness, contrast, etc). Examiners viewed periapical radiographs with Xray Vision DCV software (Apteryx Inc, Akron, OH), and CBCT images with Carestream 3D Imaging software (Carestream Health Inc., Rochester, NY) using oblique slicing (coronal, axial, and sagittal planes).

Examiners independently viewed the images in sequential order on a laptop computer with a 15.6-inch monitor (ThinkPad, Lenovo, Morrisville, NC). They viewed and scored digital radiographs first and CBCT images second using a grading scale of subjective confidence: 1- definitely fractured, 2- uncertain, 3- definitely not fractured. Examiners were allowed to interactively view images within the capabilities of the software program with viewing breaks and no time limits.

DATA ANALYSIS

For statistical analysis, specimens scored “definitely not fractured” or “uncertain” were considered negative for fractures. Examiner interpretation of the presence or absence of a VRF was compared to the true nature of the specimen (gold standard) using kappa statistic. The average sensitivity and specificity of detecting VRFs with CBCT and PA radiographs were calculated in order to compare the results of this study with previous studies (20). Sensitivities were also calculated for complete and incomplete fractures, and for natural and artificially induced fractures. Kappa statistic was used to determine inter-examiner reliability.

RESULTS

Kappa values comparing the examiners' interpretation of CBCT images and PA radiographs versus the gold standard (fractured or not fractured) are outlined in Table 1.

TABLE 1. Kappa values of "Examiner versus Gold Standard"

Examiner	CBCT	PA
1.	0.115	0.138
2.	0.231	0.192
3.	-0.077	0.269
Average	0.089	0.166

The kappa values for examiners interpreting CBCT scans ranged from "less than chance" to "fair" agreement. The values when interpreting PA radiographs imply "slight" to "fair" agreement (22). The average kappa values among the examiners were 0.089 (slight agreement) for CBCT scans and 0.166 (slight agreement) for PAs. Inter-examiner agreement is outlined in Table 1b. The values indicate a "less than chance" to "moderate" agreement.

Sensitivities and specificities of CBCT scans and PA radiographs are outlined in Table 2. The average sensitivity and specificity of detecting VRFs with CBCT and PA radiographs were not statistically significant ($p=0.1616$) and ($p=0.7794$), respectively.

TABLE 2. Sensitivity and specificity of CBCT scan and PA radiograph interpretation

Fracture Type

Test		Average	Complete	Incomplete	Natural	Artificial
CBCT						
	Sensitivity	**0.42**	**0.83**	**0.32**	**0.29**	**0.68**
	Specificity	**0.67**	**--**	**--**	**--**	**--**
PA						
	Sensitivity	**0.27**	**0.61**	**0.26**	**0.13**	**0.64**
	Specificity	**0.89**	**--**	**--**	**--**	**--**

Regarding fracture type, there was a statistically significant difference between the sensitivity of CBCT scans in detecting complete versus incomplete fractures (p=0.0324). The ability for examiners using the CBCT to detect artificial fractures was higher than natural fractures, but the difference was not statistically significant (p=0.126).

DISCUSSION

Since endodontically treated teeth restored with a post system can create wedging forces that may induce a VRF, specimens selected were teeth often restored with a post. No root canal fillings, restorations, or posts were placed into the prepared canals prior to scanning to eliminate the possibility of artifacts and beam hardening created by these restorative materials. Teeth with single canals were used to eliminate the superimposition of additional roots and increase the likelihood of detecting the fracture.

Observers scored specimens as “fractured,” “not fractured,” or “uncertain.” However, a dichotomous scale was used for data analysis. The “uncertain” group was considered “not fractured” because clinically, an endodontist would not extract a tooth if he was uncertain the tooth was fractured.

Sensitivity and specificity tests have little validity if the involved examiners have a low level of agreement (22). Here, they were calculated here for the sake of comparison to previous published studies. We prefer to report “accuracy” and “precision” due to examiner subjectivity. Accuracy is a measure of being able to identify whether the root is fractured or not fractured. In order to determine accuracy, kappa values were used to compare examiner scores versus the gold standard in detecting fractures. The average kappa values among the examiners were 0.089 and 0.166 for CBCT scans and PAs, respectively. These values illustrate very low accuracy in detecting VRFs with either the CBCT or PA radiographs.

Precision is the ability of all examiners to agree, whether their scores are accurate or not. Precision was also determined with kappa statistic comparing examiner scores against one another. Similarly, the values were low indicating a high degree of subjective variability in interpreting the images and the difficulty the examiners had in agreeing with each other.

Twelve of twenty-six specimens in the experimental group were naturally fractured. By including them we could later compare the ability to detect them versus those artificially induced. Although not statistically significant, more artificial fractures were detected using both CBCT and PAs. It is possible that fracturing the tooth on the bench-top creates larger fractures that are more easily detected.

A "complete" fracture propagates from the canal to the extraradicular surface buccolingually or mesiodistally. An "incomplete" fracture extends to only one aspect of the root. Complete fractures were more easily identified and the difference was statistically significant with CBCT scans. These fractures may be more likely to have separation of tooth segments.

The literature referencing the ability to detect VRFs is limited. Although there was a high detection rate with all radiographic modalities, Kambungton et al. determined there was not a significant difference in using F-speed film, a CMOS digital sensor or a limited-FOV CBCT to detect VRFs (19). Other studies concluded that CBCT provided a more accurate diagnosis of a VRF relative to periapical images (20,21). These studies differ from ours in methodology. Hassan et al. artificially induced all fractures and evaluated specimens using a 10X16cm FOV with an isotropic voxel size of 0.25mm. Similarily, Varshosaz et al. artificially created all fractures and used a larger FOV and voxel size. With a smaller FOV, smaller voxel size and likely smaller sized fractures, we were not able to detect as many fractures. In our study, when we evaluate only complete fractures, our sensitivity is 0.83, which favorably compares with others (20). Our reported sensitivity for detecting incomplete fractures with CBCT is 0.32. No others distinguish between complete and incomplete fractures.

In an in vivo case series, a sensitivity of 88% and specificity of 75% was calculated employing a limited-FOV CBCT to identify VRFs (18). If a VRF was suspected after clinical examination and periapical radiographs, a CBCT scan was exposed and the presence or absence of the VRF was confirmed through direct visualization during surgical exploration. Other identifiers such as disruption in the periodontal ligament or bone loss enabled an observer to confirm a suspected VRF. These indicators are not available with in vitro studies using extracted teeth.

All evaluators in our study reported a high number of false positives when using the CBCT. Clinically, this could result in inappropriate treatment planning including unnecessary extraction. False positives could result from mis-identification of other canal and root anatomy such as an accessory canal in a non-fractured specimen. It may also be due to the decreased contrast to noise ratio encountered with higher resolutions (15). Future studies should consider if smaller voxel size and higher resolution negatively impact the ability to detect root fractures. Others should focus on clinically evaluating fractures with CBCT and reporting the accuracy of the technology when the tooth can be evaluated with the surrounding bone. Better guidelines for evaluators (and clinicians) could also limit the number of false positives.

CONCLUSION

There was poor accuracy and examiner precision in identifying a VRF using a limited-FOV CBCT scan. VRFs were not detected unless there was clear separation of tooth segments, such as with a complete fracture. Therefore, sole reliance on a CBCT scans to diagnosis a VRF should not be practiced until technology improves. A thorough clinical examination completed in conjunction with diagnostic images is still the most accurate way to approach this diagnostic dilemma.

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